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EBSD Analysis of the Structural State of the Cu-Zn-Mn-Al-Fe-Ni Alloy after Hot Deformation

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Abstract. The structural state of the Cu-Zn-Mn-Al-Fe-Ni alloy after high-temperature forming is studied. It is reported that in the section of a ring blank there are two structural zones with different amounts of strain. It has been found by EBSD analysis that in the maximum strain zone the alloy suffers dynamic recrystallization under forming, whereas in the minimum strain zone there is only dynamic polygonization, coarse grain boundaries become strengthened, this being accompanied by an increase in the values of hardness to 300 HV 0.2; this causes their embrittlement and brittle grain-boundary cracking of the blank at room temperature under the effect of residual stresses.

INTRODUCTION

The Cu-Zn-Mn-Al-Fe-Ni alloy is alloyed brass designed for producing machine parts by high-temperature forming. It was reported earlier in [1] that the alloy is based on the ordered CuZn β' -phase; under cooling after hot deformation, on the grain boundaries of this phase there appears an α -solid solution of alloying elements in the copper lattice. At high rates of cooling, the α -phase is completely missing in this alloy. Besides the α and β' phases, in the alloy there are (Fe,Mn)₅Si₃ silicides amounting to not more than 3 vol% and Pb in the amounts below 2 vol%. The main drawback of this alloy is the danger of blank cracking after hot deformation. The examination of the surface of cracks appearing in ring blanks, made of this alloy, after high-temperature forming reveals that, under the effect of internal residual stresses, there occurs brittle fracture by the mechanism of grain-boundary cracking [2]. To estimate the structural state of the alloy after hot forming of rings, it is expedient to use the potentialities of EBSD analysis enabling one to determine the texture, grain misorientation and the extent of recrystallization [3, 4]. The aim of this study is to determine the structural state of the hot-formed Cu-Zn-Mn-Al-Fe-Ni alloy by EBSD analysis and to find out the reasons for ring blank cracking.

MATERIALS AND RESEARCH METHODS

The Cu-Zn-Mn-Al-Fe-Ni alloy had the following chemical composition, wt %: 34.7 Zn, 3.0 Mn, 2.3 Al, 0.5 Fe, 0.4 Ni, 0.16 Si, 0.15 Pb and the rest Cu. The structure of a ring blank was studied after high-temperature forming with preheating to 780 °C (the duration of holding at this temperature was 12 min). After forming, the blank was blown around by cold air in order to prevent excessive grain growth. Cracking occurred after ring cooling. The microstructure of the sample cut out near the crack was studied, Fig. 1. The metallographic analysis was performed by a Neophot 21 optical microscope, and the EBSD analysis was made with the aid of the HKL Channel 5 software complex on a Tescan Vega II XMU raster electron microscope with an HKL Nordlys F+ accessory (Oxford Instruments, UK). The texture of β' -grains was determined and maps of orientations, recrystallization and stresses were constructed.



FIGURE 1. Physical configuration of the ring

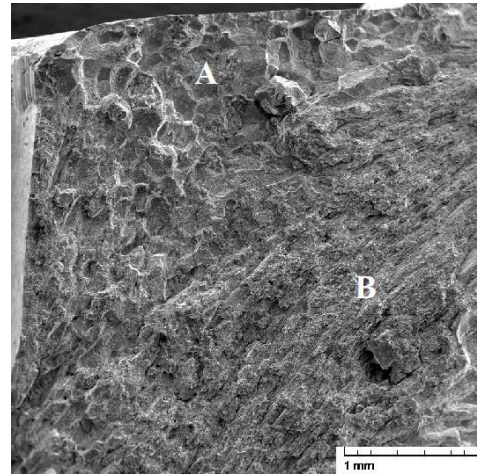


FIGURE 2. Ring fracture surface relief

RESULTS AND DISCUSSION

The surface of the crack resulting from hot forming of a ring blank was studied earlier in [2], where it was reported that there were two zones on the fracture surface, namely, zone A with large (up to 0.3 mm) β' -grains of brittle fracture and zone B, with deformed oblong grains, which fractured by the ductile mechanism with a distinctive dimple fracture (Fig. 2). When the ring blanks were heated to 780 °C and held at this temperature for 12 min, β' -grain recrystallization occurs; therefore, the grain size increased to reach 0.3 mm (before forming, the grain size did not exceed 0.15 μm). In the course of forming, the blank undergoes plastic deformation, it being minimum in the A zone and maximum in the B zone. This is confirmed by a comparison of the orientation maps for the A and B zones – the A grains are misoriented (Fig. 3a), whereas the alloy in the B zone is characterized by a deformation texture (Fig. 3b).

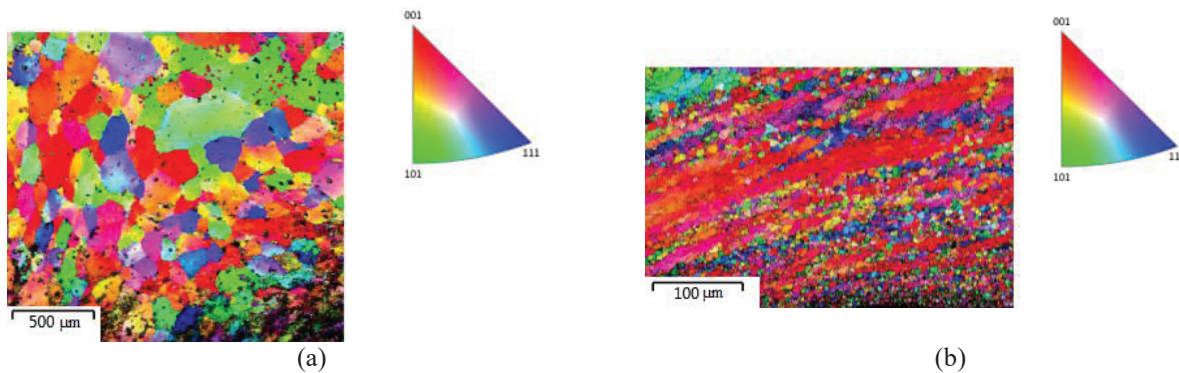


FIGURE 3. Orientation maps for the ring blank alloy in the A (a) and B (b) zones

As is known, dynamic recrystallization occurs in blanks under hot deformation, with metadynamic recrystallization occurring immediately after the deformation ends [5]. These processes are more active under two conditions, which are maximum alloy overheating above the recrystallization temperature or maximum amount of strain. Holding for 2 min at 780 °C ensured uniform heating of the whole section of the ring blank; therefore, the difference in the dynamic recrystallization processes in the A and B zones stems only from different amounts of strain. The analysis of direct and inverse pole figures on the right in the A and B zones demonstrates that the B zone is characterized by the (100) axial texture, whereas in the A zone there are chaotically located broad peaks of intensity. Since the amount of strain in the B zone exceeds significantly that in the A zone, dynamic recrystallization is much more in-

tensive in the B zone. On the recrystallization maps there are distinctly visible new small recrystallized or sub-crystalline grains in the B zone and only sub-crystalline grains with isolated recrystallized ones in the A zone (Fig. 4). One should take into account the peculiarities of constructing the recrystallization maps, which are provided by the software package, namely, the succession is as follows: first grains are reconstructed, then the program measures average misorientations within a grain. If the average misorientation angle in a grain exceeds 2, the grain is identified as deformed. Some grains consist of subgrains. In this case, if the internal misorientation in a subgrain does not exceed 2 and exceeds 2 from subgrain to subgrain, then the grain is identified as substructural (polygonized). If the average misorientation angle does not exceed 2, the grain is recrystallized. It is known from [5] that a feature of dynamic and metadynamic recrystallization, as distinct from static one, is the appearance of new hardened grains with high dislocation density. On the boundaries of large β' -grains in the A zone there are deformed small grains (Fig. 4a). Most probably, they are new (recrystallized) grains, which, as a result of dynamic and metadynamic recrystallization, are characterized by a high degree of misorientation; therefore, they are identified by the program as deformed. The results of microhardness measurements through the grain section in the A zone have shown that the near-boundary regions of the alloy are characterized by the values 300 HV 0.2, whereas in the bulk the hardness values are as low as 170HV 0.2. The hardening of the boundaries of large β' -grains in the A zone causes the brittle grain-boundary cracking of the alloy affected by internal stresses resulting from the cooling of the formed blank. In the B zone there are small β' -grains resulting from dynamic polygonization and recrystallization (Fig. 4b); therefore, this zone fractures in a ductile way and, most probably, it is the rupture area in crack propagation.

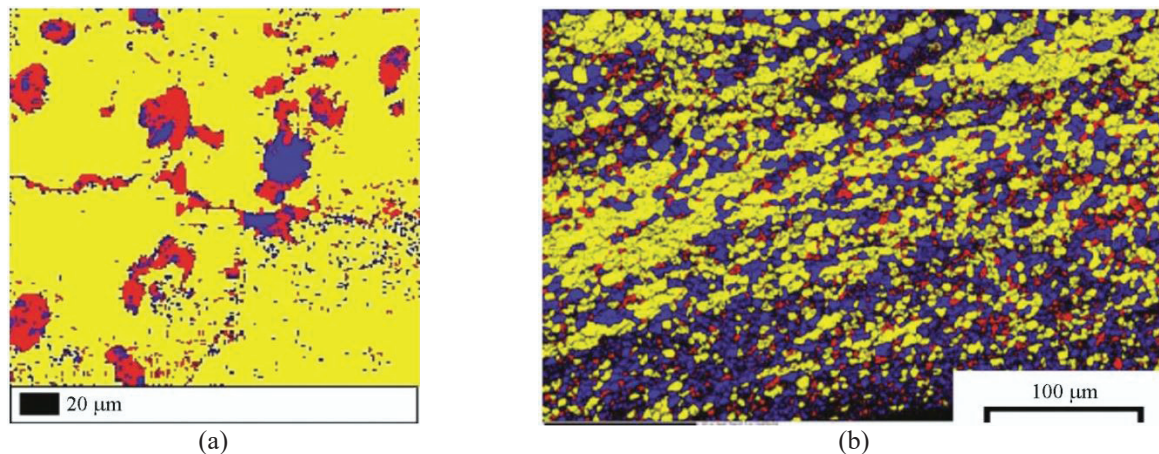


FIGURE 4. Recrystallization maps: (a) – A zone; (b) – B zone; blue – recrystallized grains, yellow – sub-crystalline structure, red – deformed grains, μm

The stress maps are constructed as follows: the program measures the maximum misorientation between two arbitrary points within one grain. Then, by the procedure of mathematical “weighing”, a certain weight value is put in correspondence to each point according to the maximum misorientation measured at the previous stage. The stress maps qualitatively characterize the change of lattice misorientations, and the maximum values of stresses on them correspond to enhanced misorientation or increased dislocation density (Fig. 5a). Dynamic recrystallization in the A zone, where deformations are not as large as in the B zone, is limited to the formation of new small grains on the boundaries of initial large grains (Fig. 5b).

The obtained data offer the following idea of the processes occurring in the ring blank under high-temperature forming: heating and holding at 780 °C before forming are accompanied by recrystallization processes, i.e. β' -grains grow in size up to 0.3 mm; brass deforms under forming, the strain being nonuniform through the section, namely, there is a region with minimum strain; therefore, the process of dynamic recrystallization is different, with a sub-crystalline structure in the A zone and a recrystallized and sub-crystalline one in the B zone. Immediately after the end of forming, metadynamic recrystallization occurs in regions with maximum strain, whereas new small grains with high dislocation density and high hardness on the boundaries of initial large grains appear in the region with minimum strain. This is why, under the effect of residual stresses, there occurs crack growth on the boundaries of the initial large β' -grain after blank cooling.

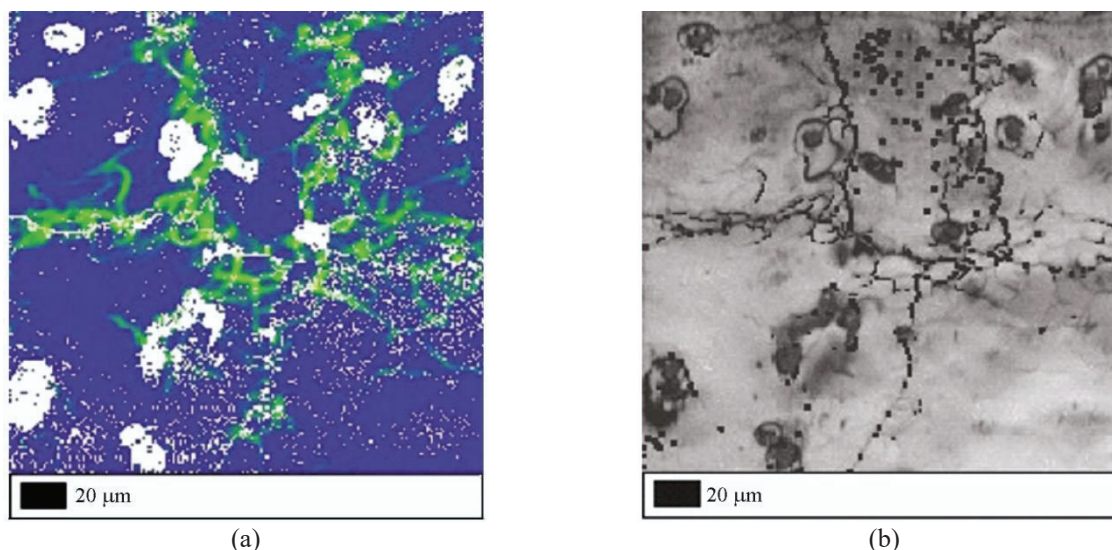


FIGURE 5. Maps of stresses (a) and contrasts (b), green – maximum stress values

CONCLUSION

The investigation made by EBSD analysis has shown that, under high-temperature ring forming, the deformation is nonuniform through the blank section. In the region with minimum amount of strain there occur dynamic polygonization and the formation of a continuous network of isolated small deformed grains with high values of hardness on the boundaries of initial large grains. This results in brittle grain-boundary cracking of blanks at room temperature under the effect of residual stresses.

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